TFAWS Interdisciplinary Paper Session

Small Satellite Solar Thermal Propulsion System Design: Initial Thermal Analysis

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THERMAL & FLUIDS ANALYSIS WORKSHOP

TFAWS
MSFC • 2017

Presented By
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Thermal & Fluids Analysis Workshop
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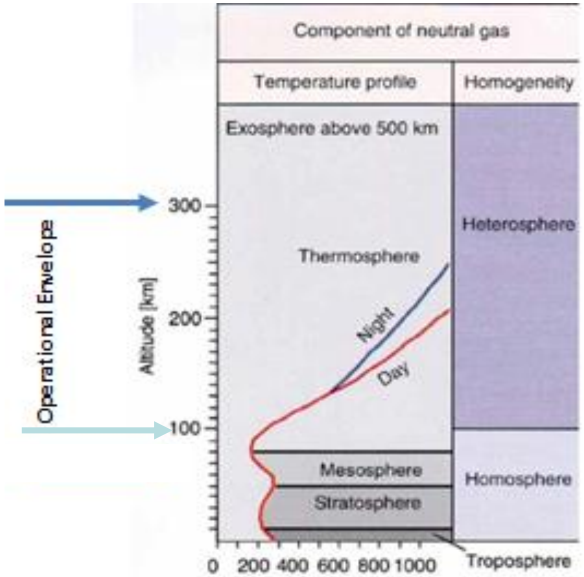
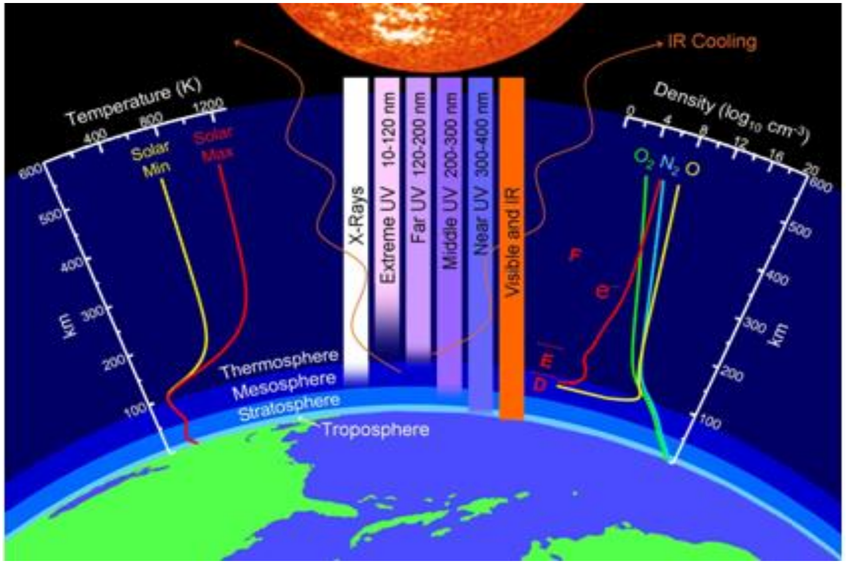
NASA Marshall Space Flight Center
Huntsville, AL

Overview

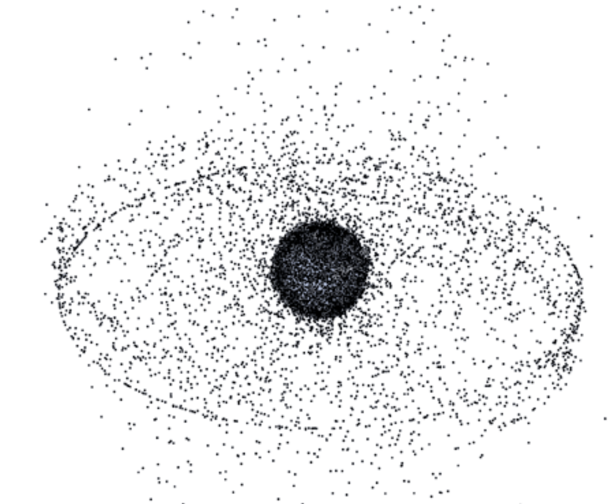
- Motivation: Address the need for propulsion
- Identify Design Constraints
- Requirements
- Current Propulsion Technologies
  - Electric
  - Chemical
  - Conventional solar thermal
- Introduce Proposed Concept
  - Overview
  - Workable engineering design
    - Heat exchangers (solar array, propellant-tank, radiator)
    - Concept integration
- Initial Propulsion Analysis
- Conclusion





Ley, Wilfried., Wittmann, Klaus., Hallmann, Willi., Handbook of Space Technology, WILEY 2009[5]http://i.i.com.com/cnwk.1d/i/tim//2010/07/15/ thermosphere.jpg

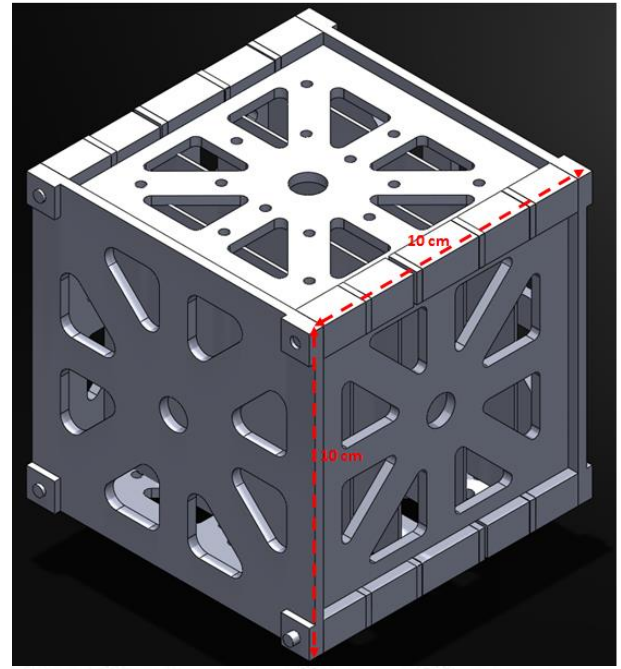
- Maintain orbit during lifetime
- Orbital changes (includes de-orbiting at the end of mission)



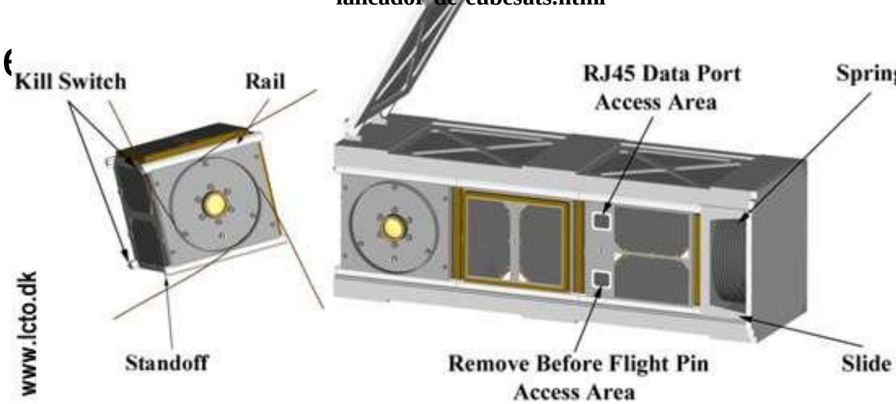
http://earthobservatory.nasa.gov/Features/OrbitsCatalog/page3.php

Design Constraints

- Size
  - 1-U
- Mass
  - Pico-satellites < 1 kg
  - Nano-Satellites 1–50 kg
- Power
  - 1 W/kg
- Supporting technologies
  - Launch mechanisms- impose form-factor constraint
- Operational
  - LEO

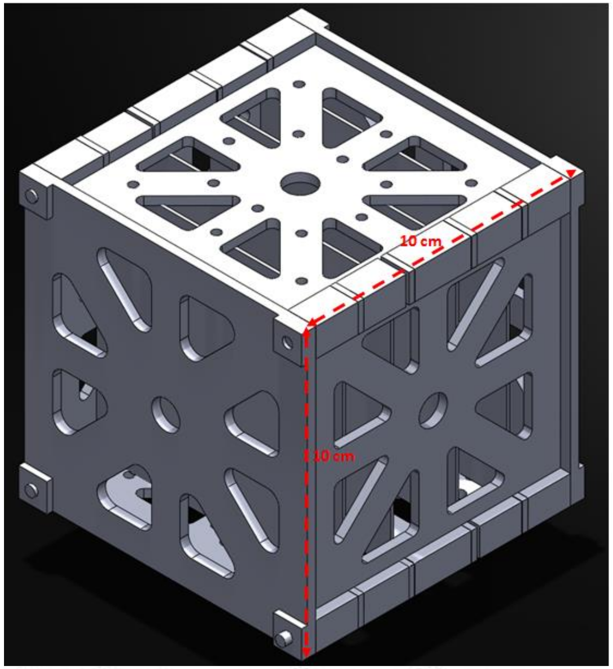


POLY-PICOSATELLITE ORBITAL DEPLOYER
http://pynoticias.blogspot.com/2012/08/p-pod-o-lancador-de-cubesats.html



Design Requirements

- Size
  - Be able to fit in 1-U
- Mass
  - Low mass
- Power
  - Low power
- Supporting technologies
  - Use current supporting technologies
- Operational
  - Use available resources



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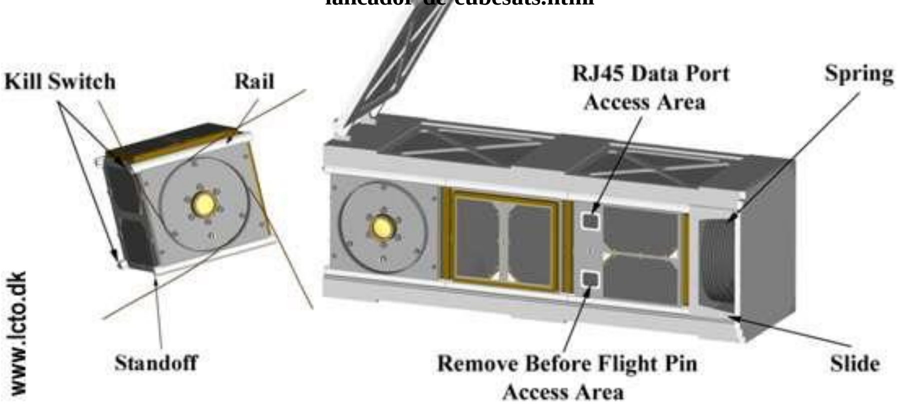
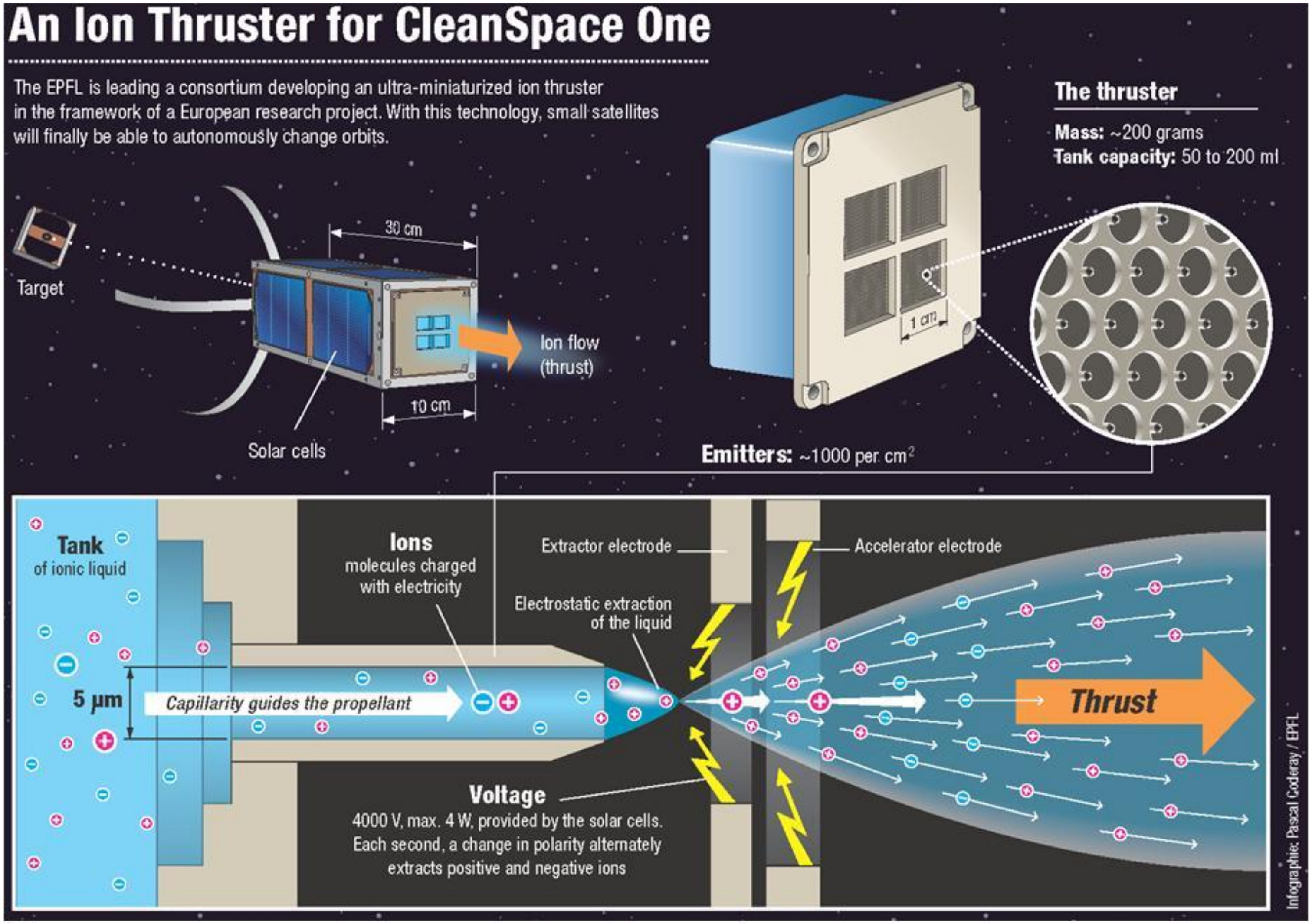


Current Propulsion Technologies

Miniature ION thrusters

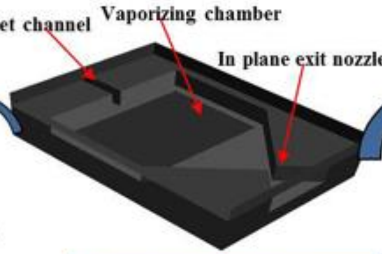


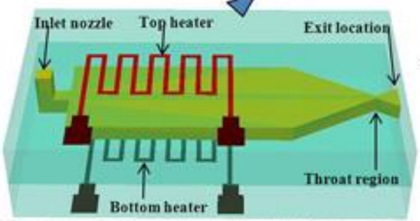
http://lmts.epfl.ch/MEMS-ion-source

Current Propulsion Technologies

Chemical thrusters

The proposed MEMS based VLM and chemical microthruster

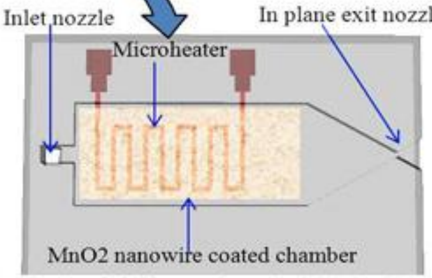




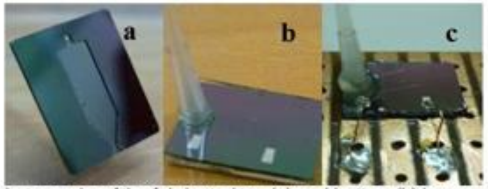
3D schematic view of complete MEMS microthruster sandwiched between top and bottom microheaters.

Targeted Specification:
Weight of satellite: 10 Kg
Years in orbit : 5 Yrs

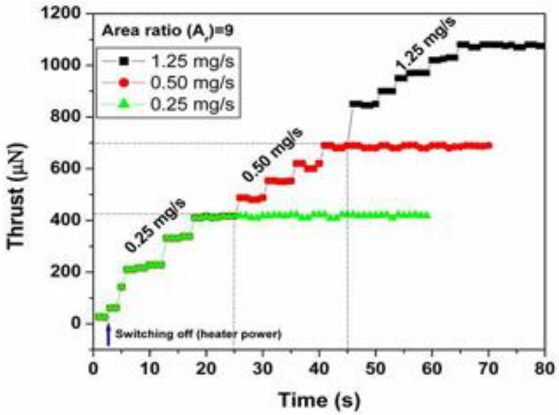
Thrust :1mN.
Chamber pressure : 1.0 bar
Propellants : H_2O2 & H2O



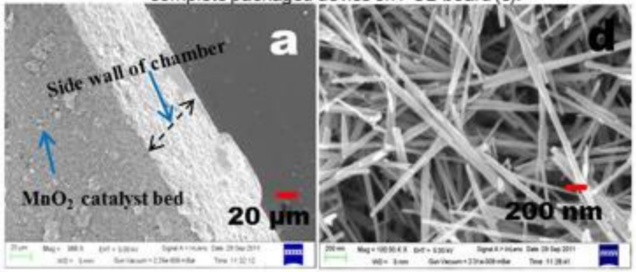
Schematic view of MnO_2 nanowire embedded microthruster showing various micromachined components.



Microphotographs of the fabricated top (a) and bottom (b) layers and complete packaged device on PCB board (c).



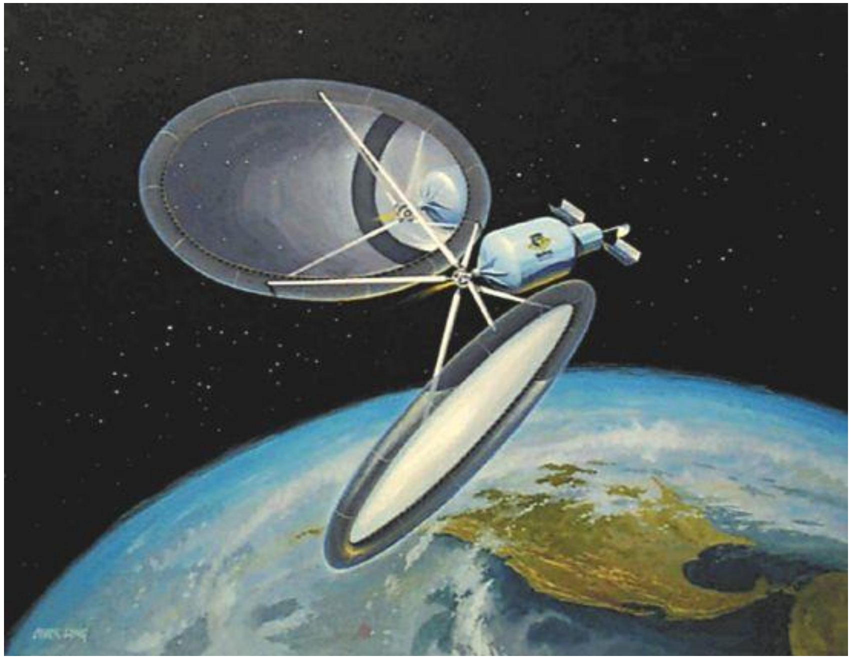
Measured thrust output for a microthruster with hydrogen peroxide delivered at various flow rates by syringe pump.



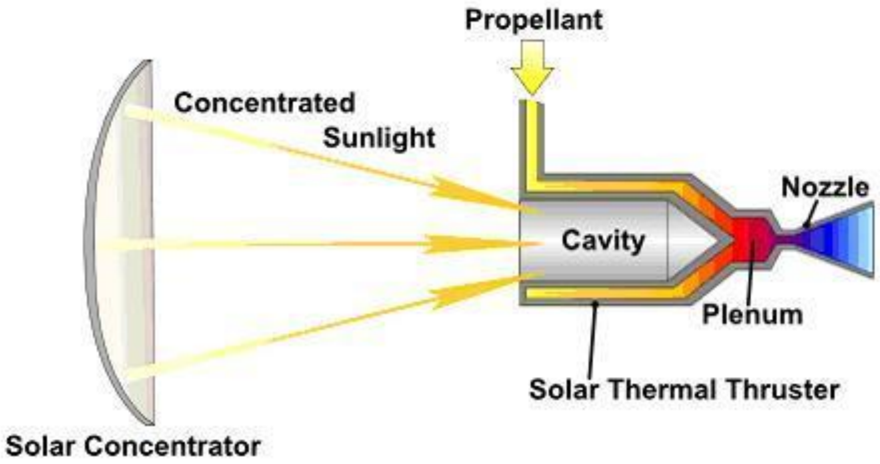
FESEM Images of MnO_2 Nanowires of various magnifications embedded in Different locations of microthruster chamber.

http://www.techpedia.in/award/project-detail/Performance-Enhancement-of-Microthruster-using-Nano-engineered-MEMS-Structure-for/1673

Conventional Solar Thermal thrusters



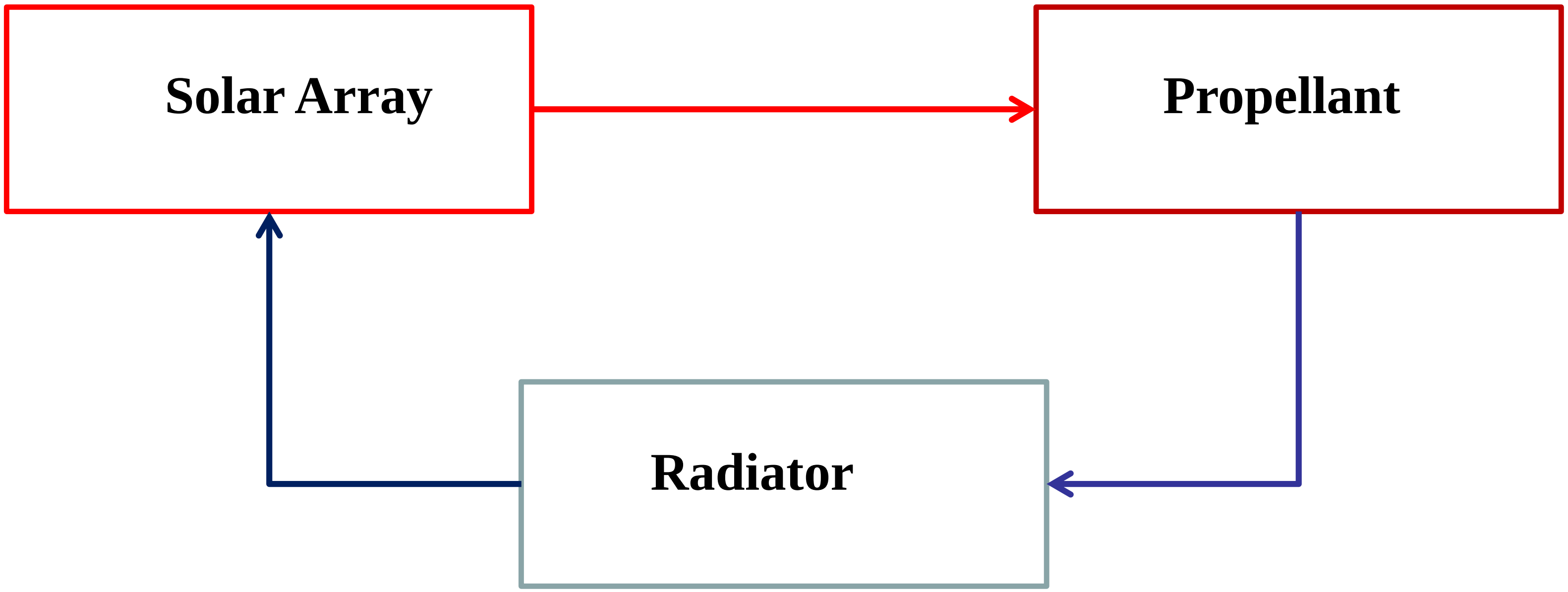
http://www.ecofriend.com/green-satellite-engines-from-pentagon-by-2008.html



http://mech-hm.eng.hokudai.ac.jp/~spacesystem/study_e.html

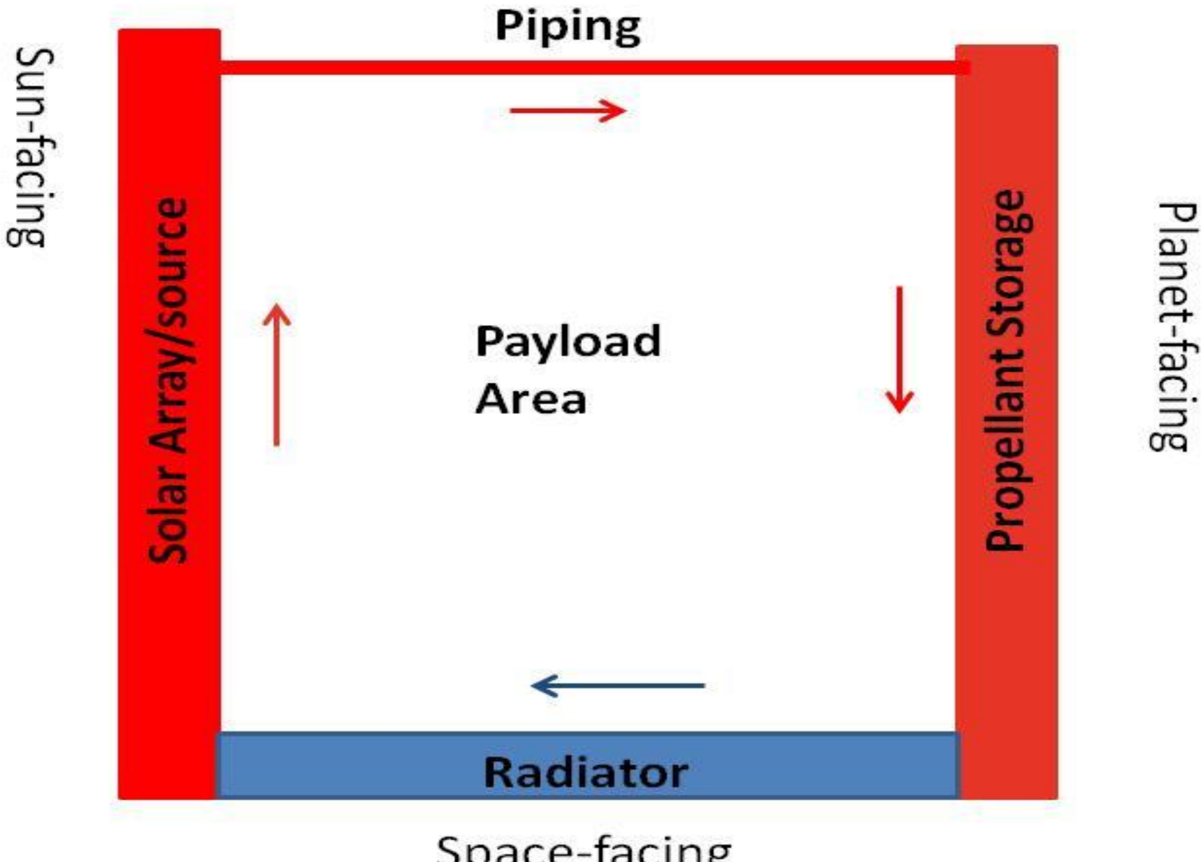
Proposed Solar Thermal Concept

- Concept revolves around moving thermal energy (form of heat) from the solar array to the propellant
- Plan on accomplishing this with a series of heat exchangers



Thermal Engineering Design

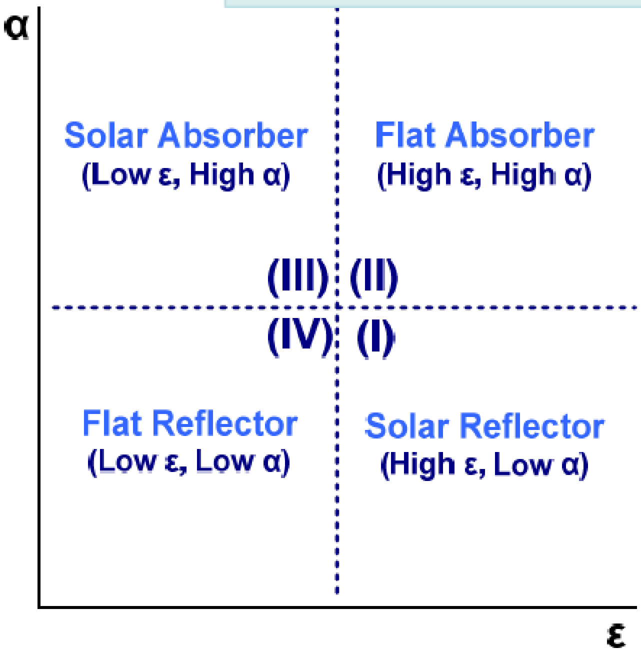
- Solar array always orientated facing the sun
- Propellant tank facing the planet
- At the heart of the **design** is understanding the temperature behavior of the solar cells in LEO



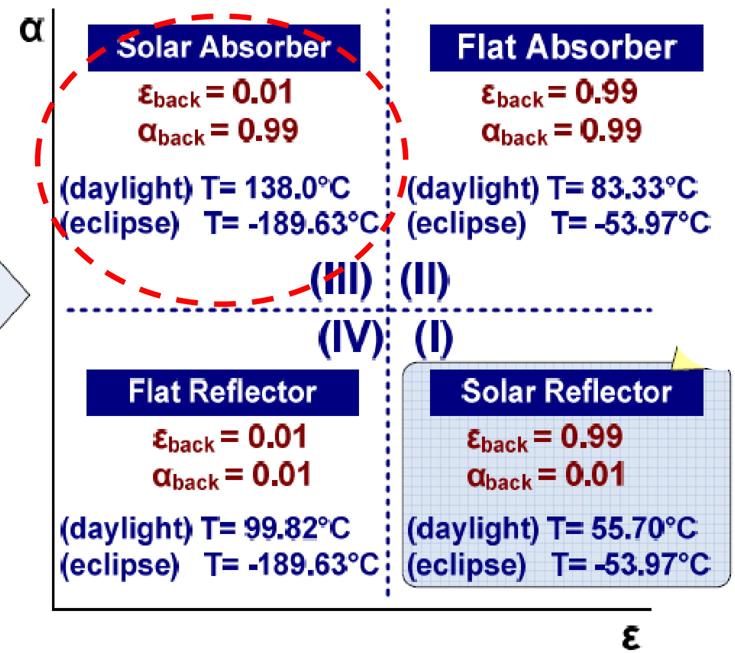
Solar Cells Surface Finishes

Look at two major characteristics: (1) Absorptivity, and (2) Emissivity

The Analytical Prediction of the Temperature of Solar Array
(for Four Ideal Surface Finishes)



4 Type Ideal Surface Finishes



Analytical Temperature Prediction of a Solar Array according to each surface type for determining the solar array backside thermal design

Kim, H-K., Lee, J-J., Hyun, B-S., Han, C-Y., ‘Thermal Design of the Solar Array in a Low Earth Orbit Satellite by Analytical and Numerical Methods’, Korea Aerospace Research Institute (KARI)

Solar-Array-Heat-Exchanger

- Consist of a single phase fluid-filled heat-exchanger pipe in contact with the solar array and a thermal insulator.

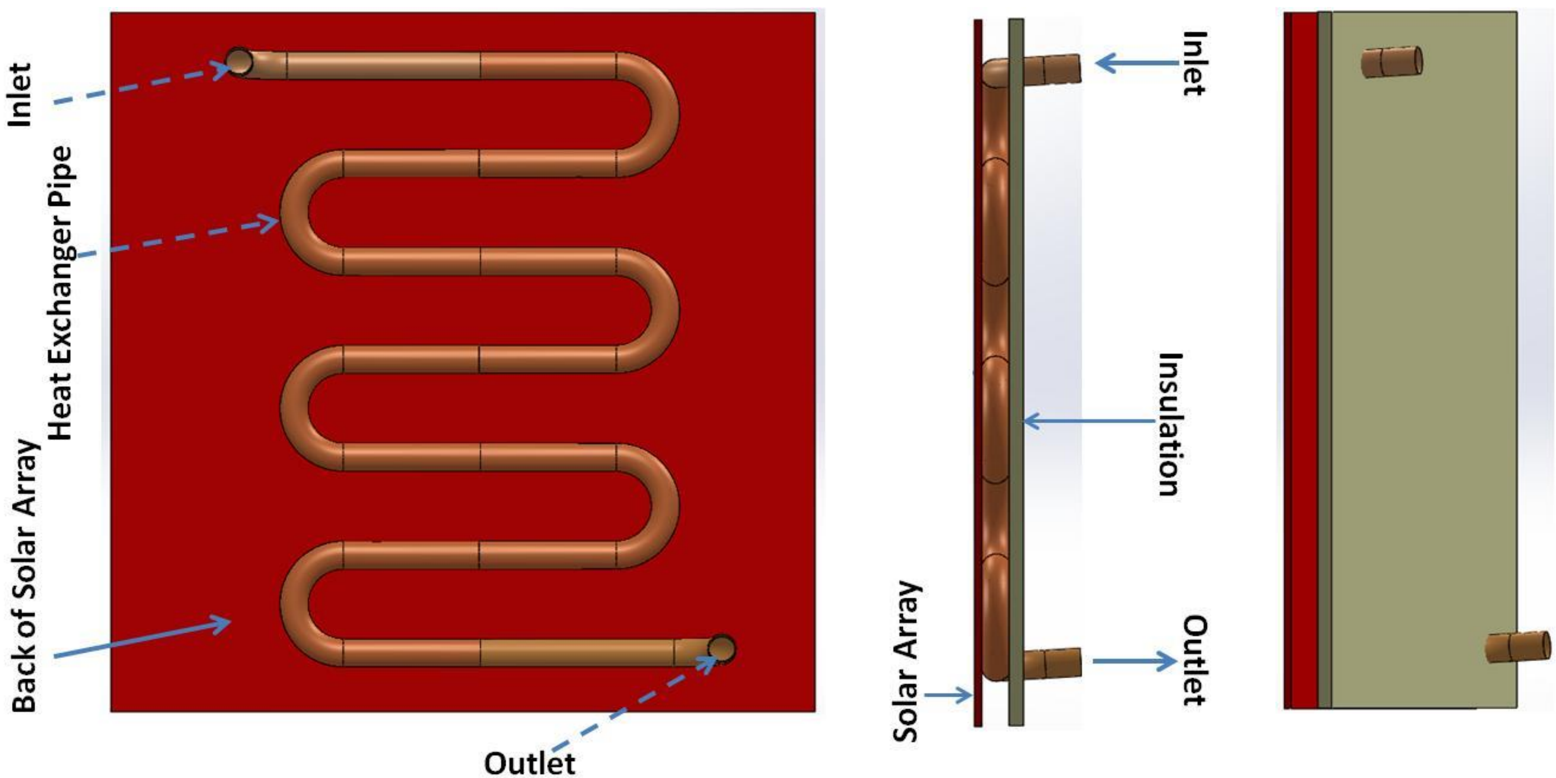
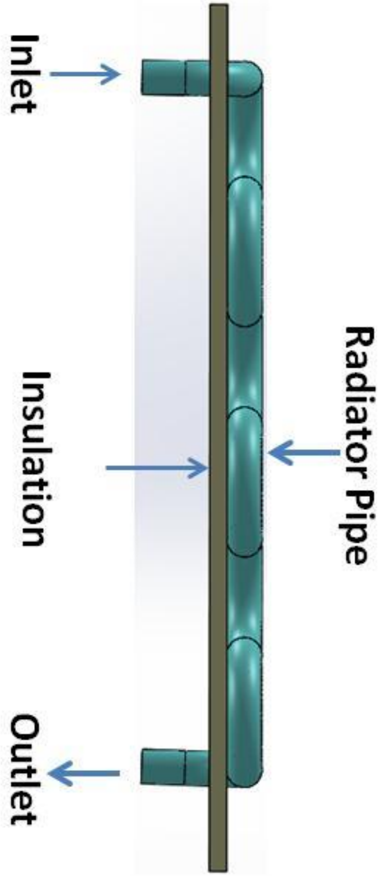


Figure 10. (a) Solar array heat pipe arrangement. (b) Side view (c) Isometric view

Radiator -Heat-Exchanger-Design

- Single-phase fluid-filled heat-exchanger pipe exposed to space.



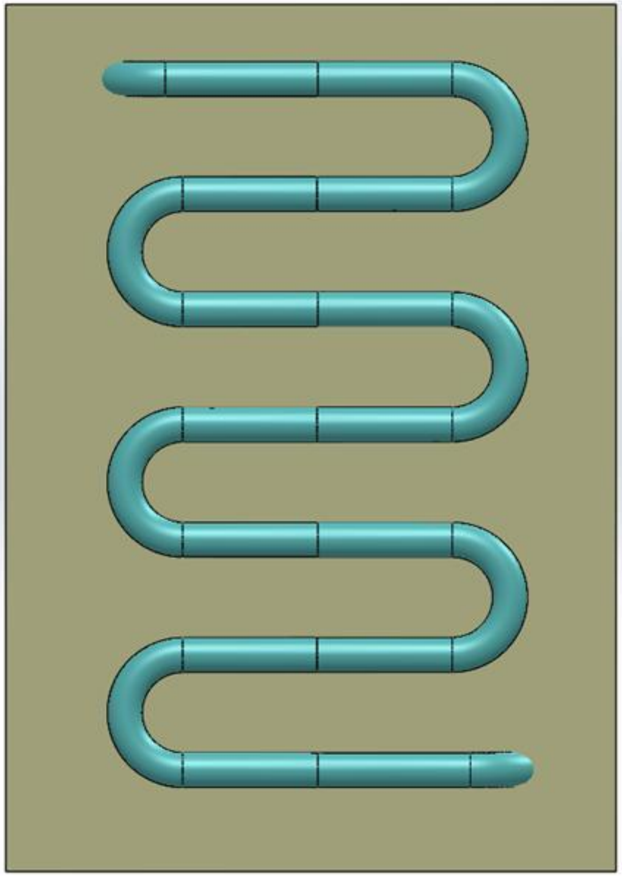


Figure 12. (a) Radiator side view **(b) Radiator top view**

Propellant-Tank-Heat-Exchanger

- Consist of a fluid-filled heat-exchanger pipe immersed in the propellant.

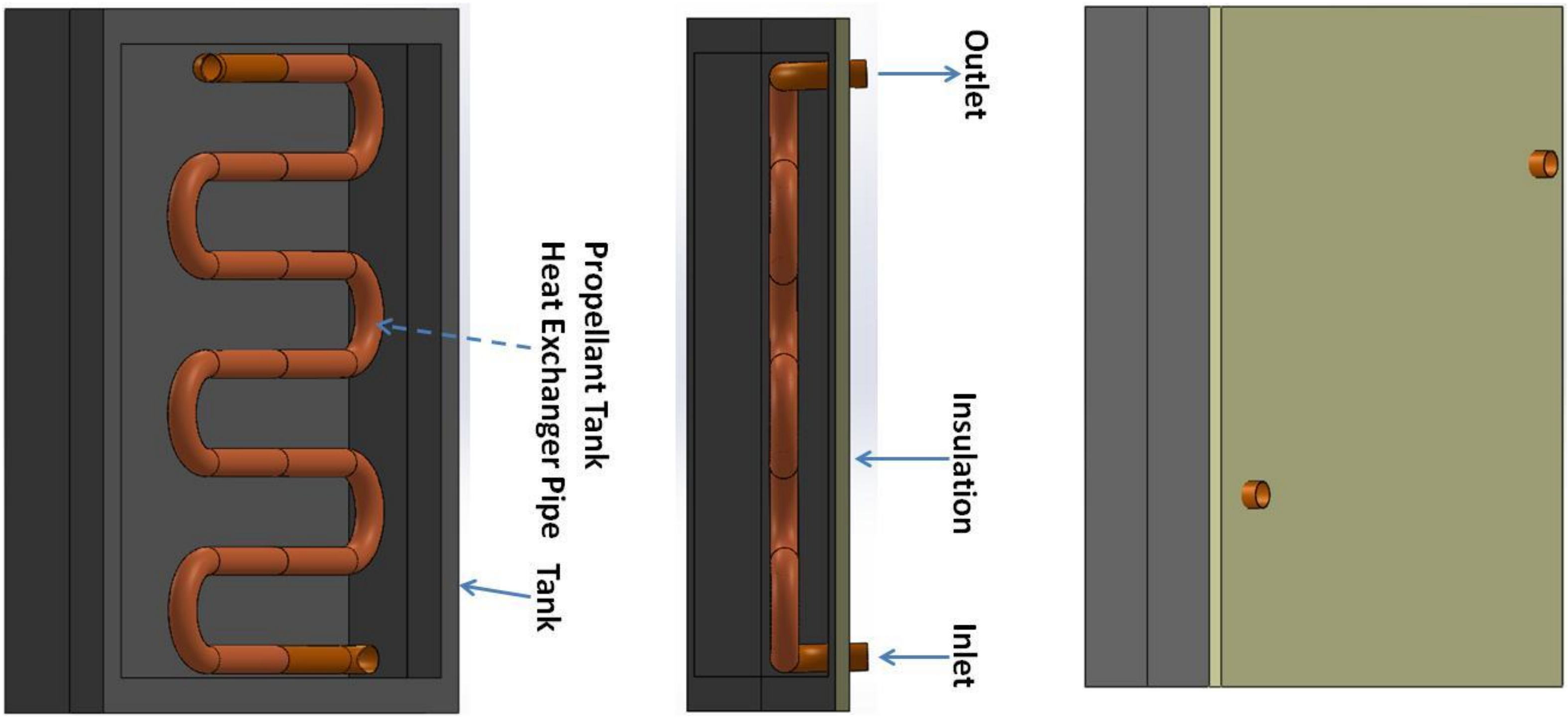
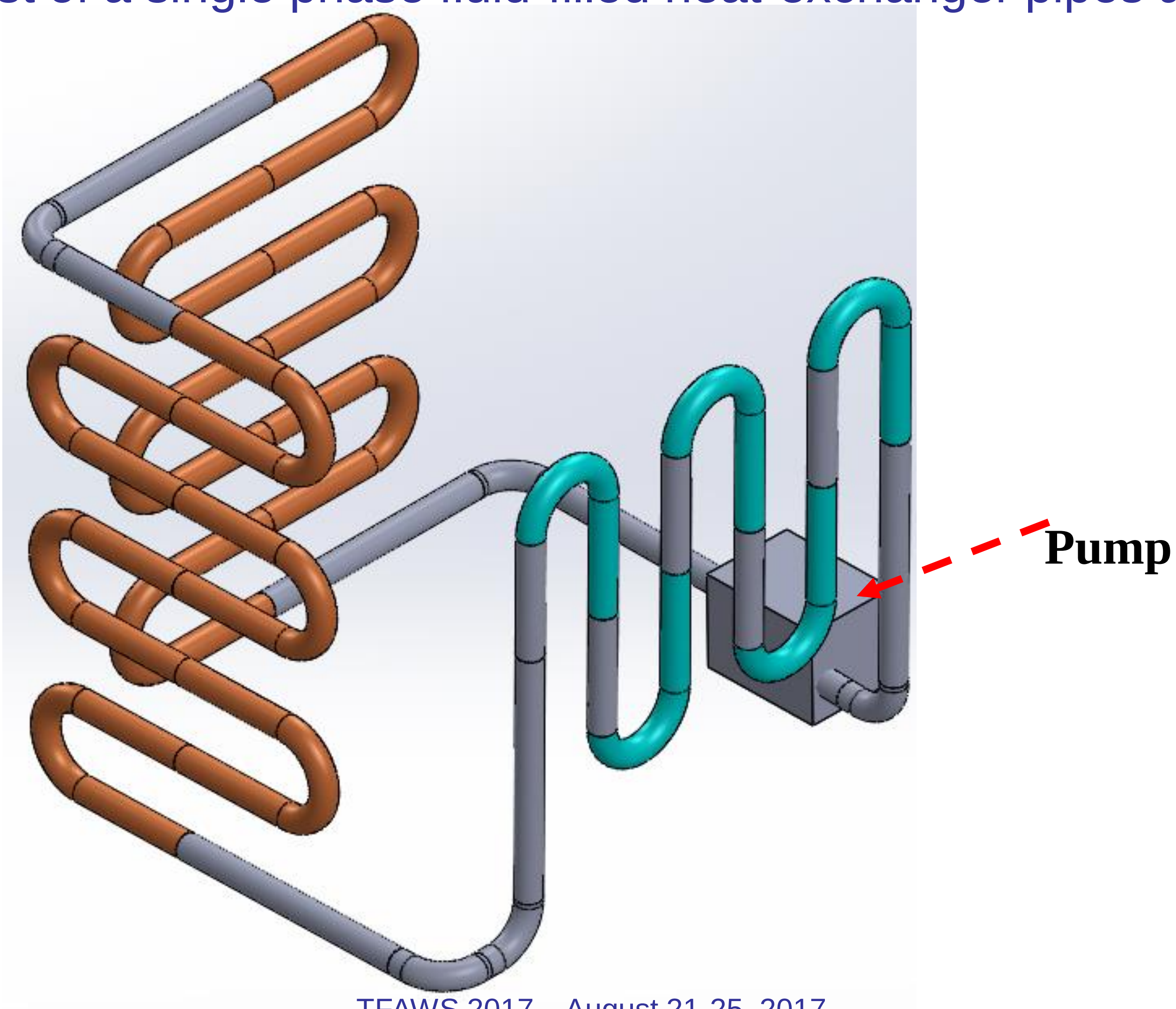


Figure 11. (a) Cross-sectional isometric view (b) Cross-sectional side view (a) Isometric view

Proposed Architecture

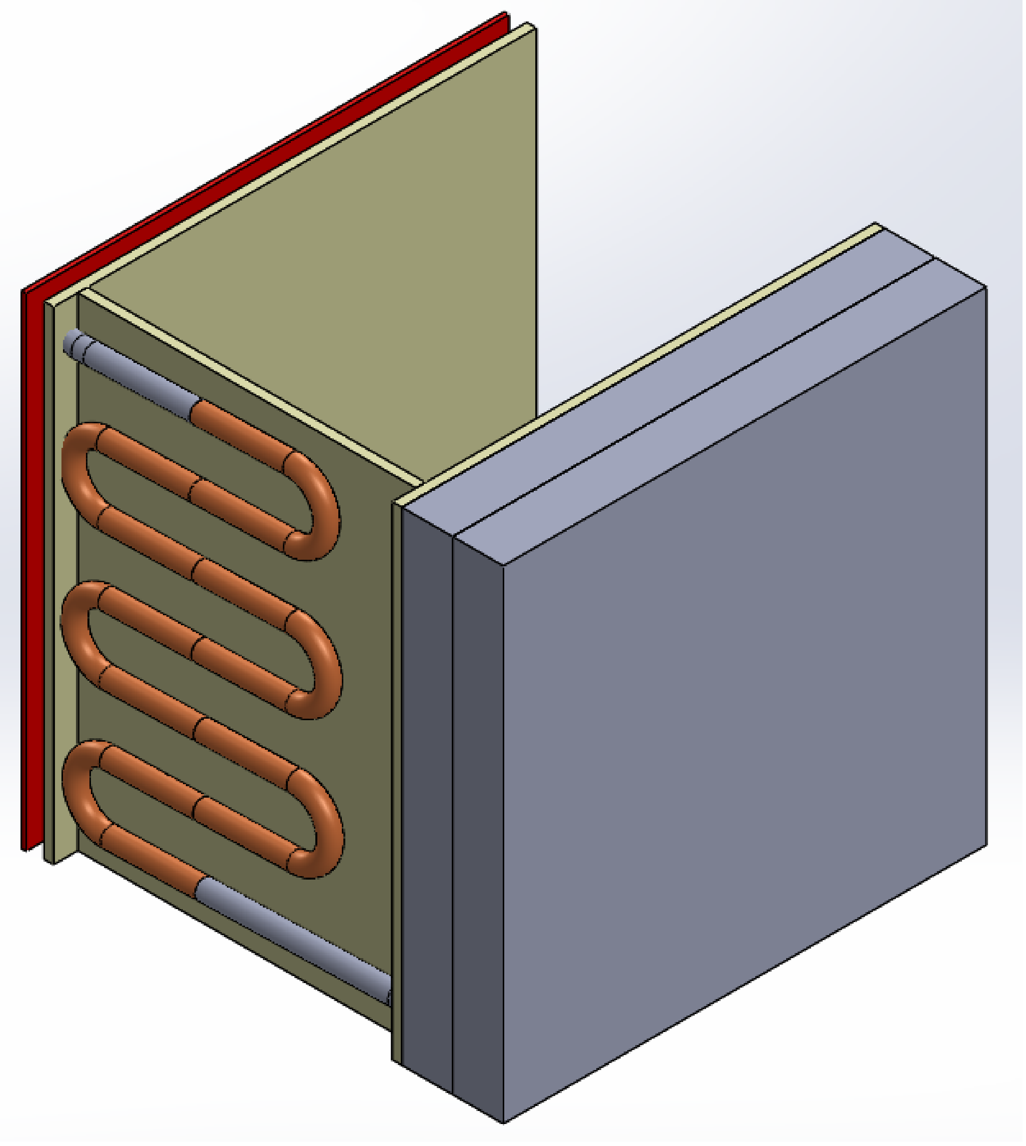
Piping-Design

- Consist of a single phase fluid-filled heat-exchanger pipes and pump.



Assembled Model

- Heat-Exchangers
- Associated piping
- Pump



Propulsion Analysis

- Using **established** relations for exhaust velocity, thrust force and specific impulse.
- **Compare**, using thrust force and specific impulse, **various technologies** under development for small satellite (Cube-Sat) propulsion.
- Compare **concentrated** solar thermal with the proposed **heat exchanger** concept (using water, ammonia, hydrogen and hydrazine as propellant choices)

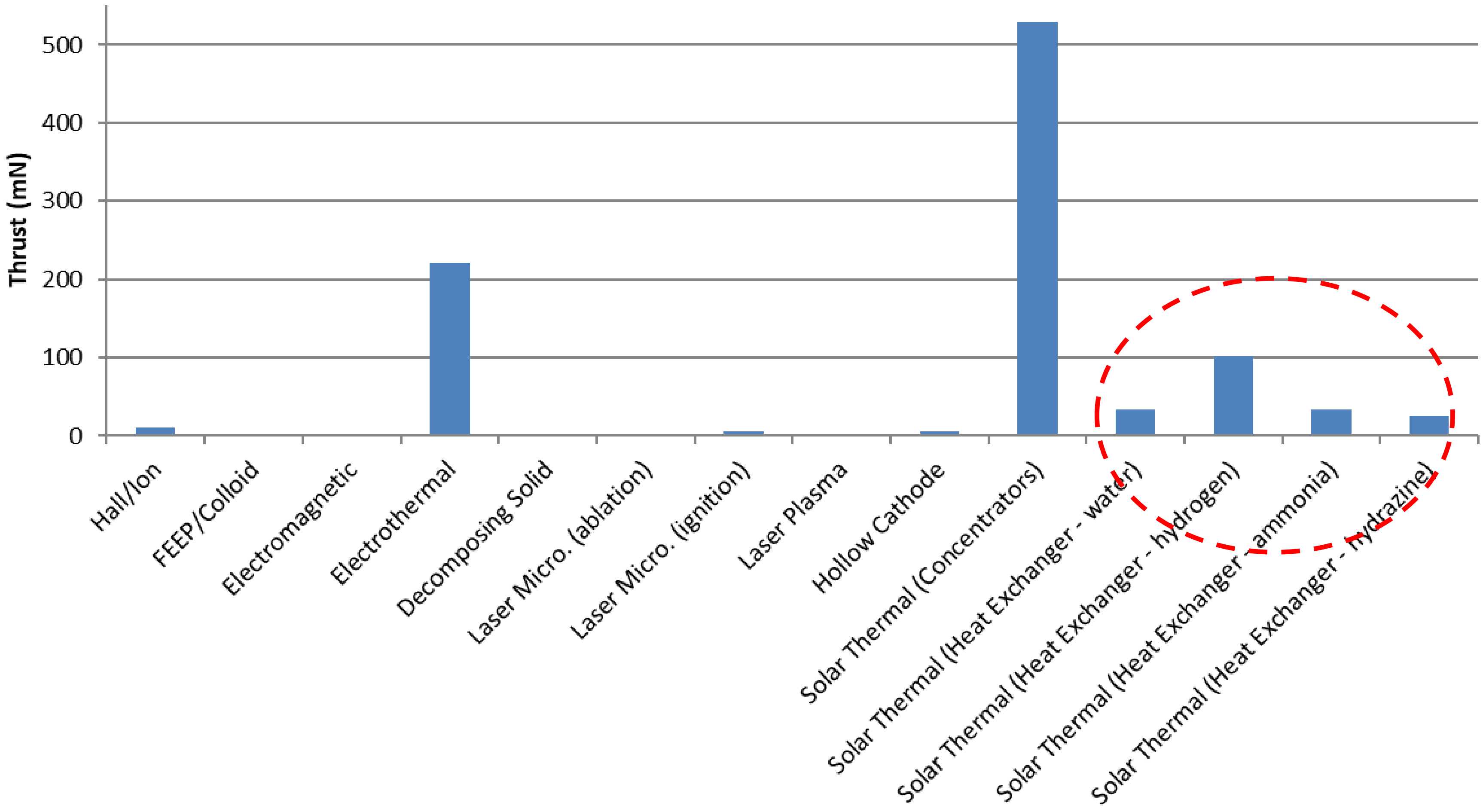
$$V_e = \sqrt{\left(\frac{2k}{k-1}\right)\left(\frac{R_* T_c}{M}\right)}$$

$$F = \dot{m} V_e$$

$$I = \frac{F}{\dot{m}\, g}$$

Propulsion Analysis – Thrust Force

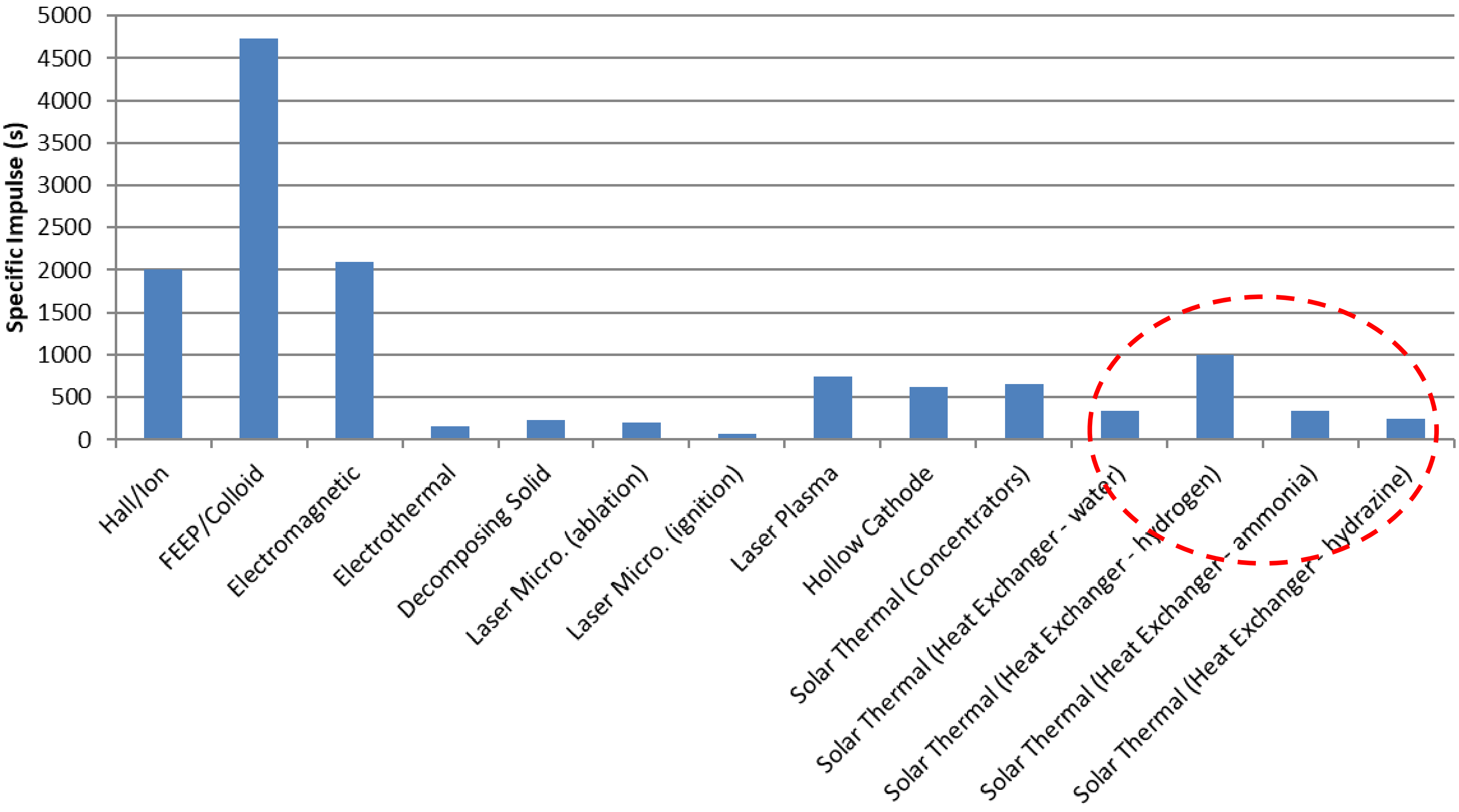
- Mass flow rate unknown



[14]**Ketsdever, Andrew, and David B. Scharfe. "A Review of High Thrust, High Delta-V Options for Microsatellite Missions." (2009**

Propulsion Analysis – Specific Impulse

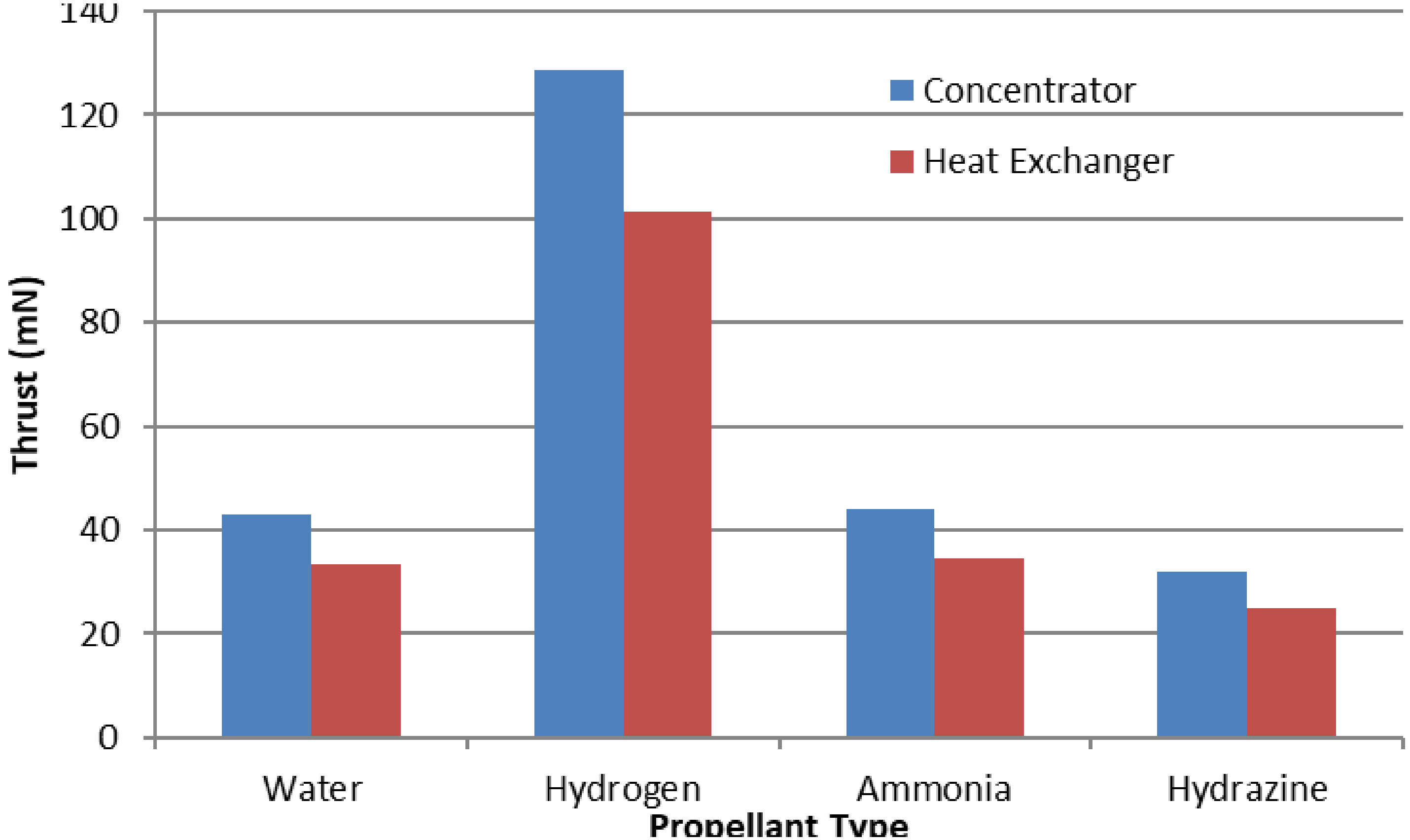
- Mass flow rate unknown



[14]Ketsdever, Andrew, and David B. Scharfe. "A Review of High Thrust, High Delta-V Options for Microsatellite Missions." (2009

Propulsion Analysis – Thrust Force

- Compare solar thermal concentrator (200 – 400 deg C) with solar thermal heat exchanger (50 – 110 deg C) concepts
- Use same mass flow rate and propellants



Propulsion Analysis – Specific Impulse

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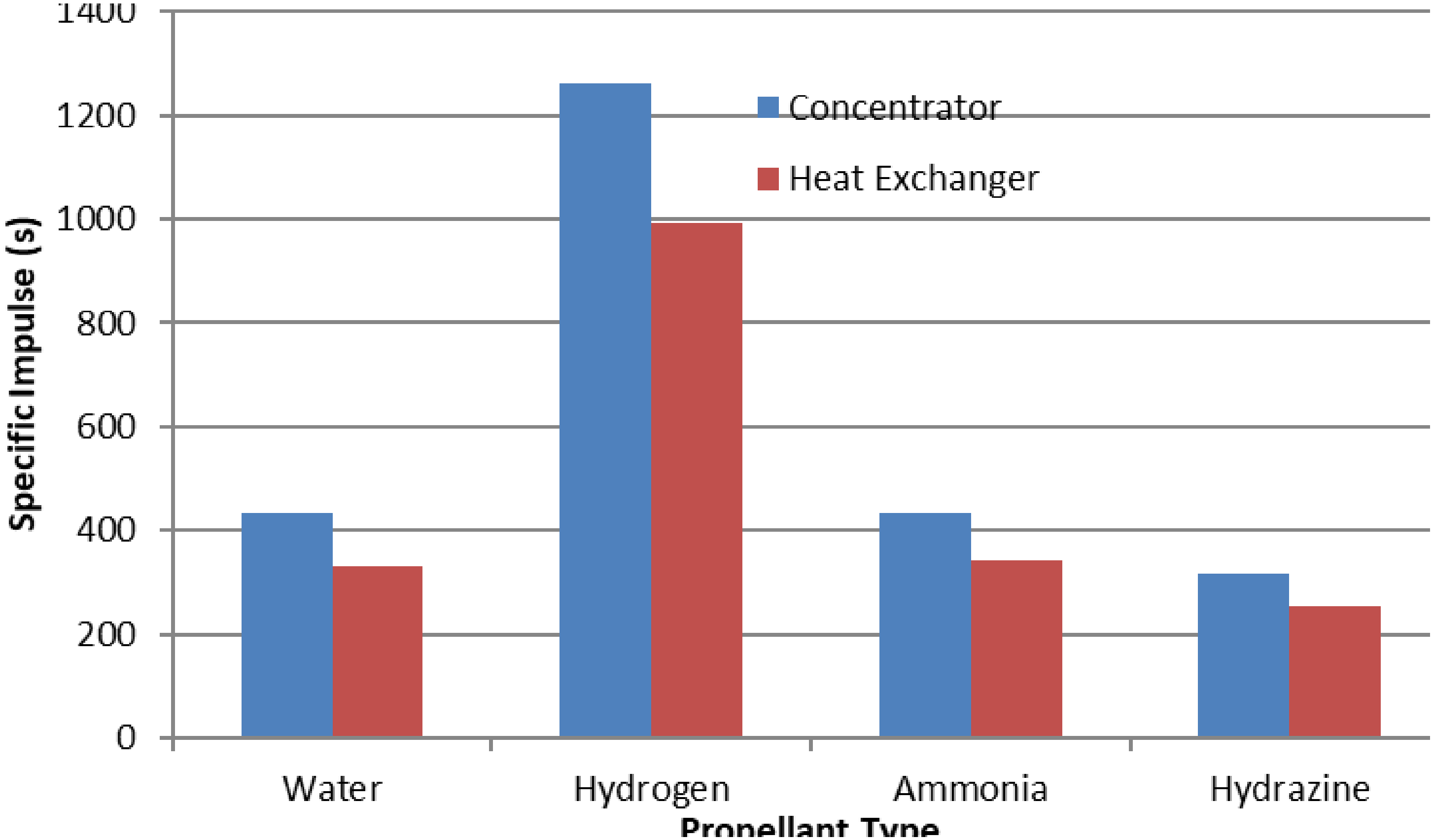
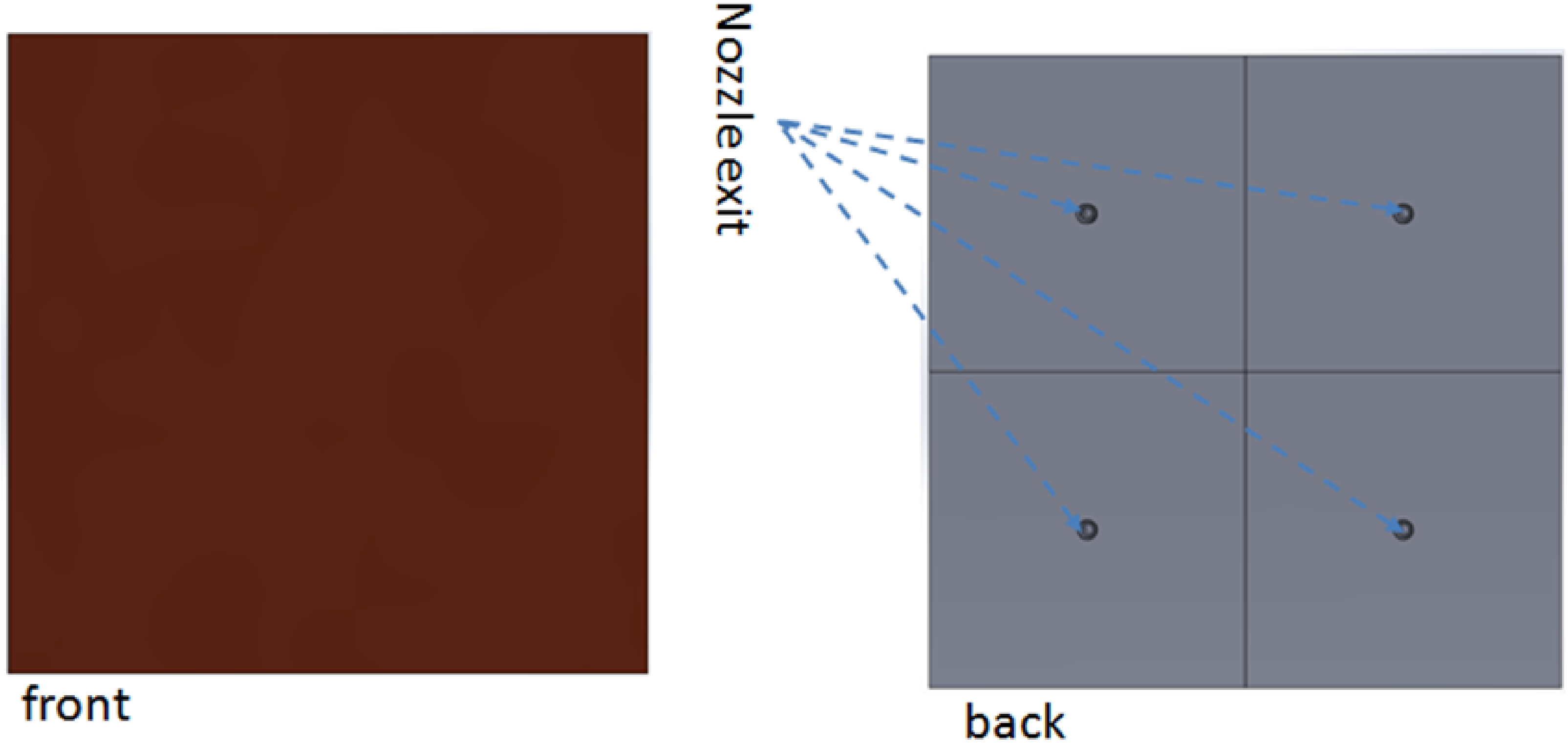
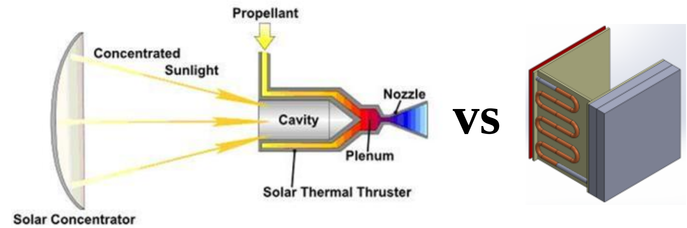


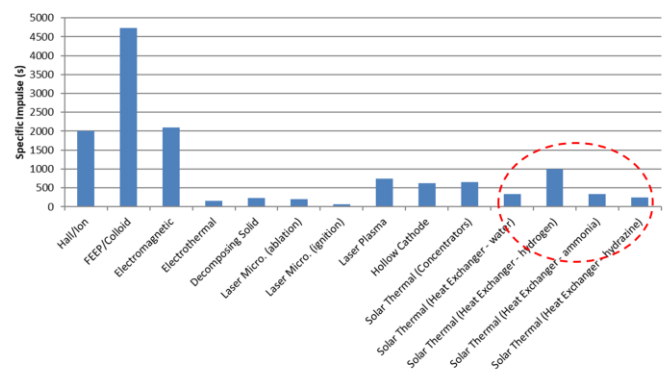
Proposed Nozzle Exit Placement

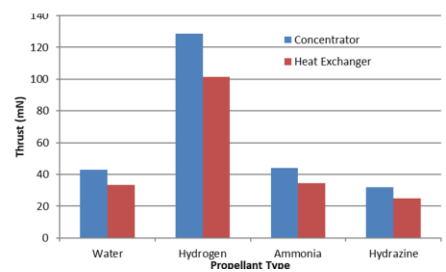


Conclusion

- We are proposing a **new concept** when looking at solar thermal propulsion.
- The proposed heat exchanger solar thermal concept **compares well** with other technologies under consideration.
- We observe from initial analysis that we can recover approximately **70 – 75%** of thrust force and specific impulse values.
- Concept warrants further investigations.







Next Phase of Study

- Continued development of computational models (with a focus on the thermal heat exchanger models)
- Do in initial experimental proof of concept.

Acknowledgements

The author would like to acknowledge the support of the NASA/NIA Langley Grant for making this initial investigation possible. The author will also like to acknowledge the work done by the USCIS AAO Washington, DC office, along with his legal and support teams.